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The Investigation of Monitoring Systems for SMAW Processes

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Abstract

The monitoring weld quality is increasingly important because great financial savings are possible because of it, and this especially happens in manufacturing where defective welds lead to losses in production and necessitate time consuming and expensive repair. This research deals with the monitoring and controllability of the fusion arc welding process using Artificial Neural Network (ANN) model. The effect of weld parameters on the weld quality was studied by implementing the experimental results obtained from welding a non-Galvanized steel plate ASTM BN 1323 of 6 mm thickness in different weld parameters (current, voltage, and travel speed) monitored by electronic systems that are followed by destructive (Tensile and Bending) and non-destructive (Hardness on HAZ) tests to investigate the quality control on the weld specimens. The experimental results obtained are then processed through the ANN model to control the welding process and predict the level of quality for different welding conditions. It has been deduced that the welding conditions (current, voltage, and travel speed) have a dominant factors that affect the weld quality and strength. Also we found that for certain welding condition, there was an optimum weld travel speed to obtain an optimum weld quality. The system supports quality control procedures and welding productivity without doing more periodic destructive mechanical test to dozens of samples.

Keywords: *Artificial neural network, monitoring, fusion arc weld.*

1. Introduction

A conventional welding system that depends on the welder's sensory perceptions: touch, sight, and hearing to evaluate the weld quality and on the welder's experience to make corrections is labor-intensive and frequently unreliable. If weld defects are detected from post weld inspection, the defective parts may result in unnecessary manufacturing cost and wasted man-hours to repair them. To solve this problem, the welding system must have in-process monitor and control of the process variables that mostly influence the weld quality [1].

The task of a weld monitoring system is to use captured signals to classify a weld into defective or nondefective groups. The signals of the welding process such as welding voltage and current can be used as variables. However, external sensors are expensive and restrict the mobility and flexibility of some automated arc welding systems. By comparison, welding voltage and current are inherent process parameters and are easy to measure. Moreover, their curves reflect many peculiarities of the welding process in their shape. Each kind of arc welding process is characterized by certain shapes of the welding voltage and the current typical for the process. Any disturbances or occurrences of faults during welding inevitably result in variation of these curves to some extent [2]. Therefore, quality assurance in arc welding may be achieved through examining welding voltage and current. Because the arc welding process involves melting and resolidification of the base material, the geometry of the resulting weld head is a good indicator of the integrity of the weld. Therefore, the geometry of the weld head: bead width, bead height, and penetration depth, along with the absence of spatter, is used as a quality indicator. Even though these measurements are used to monitor the weld pool sizes with reasonable accuracy, it is difficult to conventionally locate a sensor on the weld and to simultaneously measure the bead width, depth of penetration and dispersion of spatter [1].

Weld voltage and current comprise the basic welding electrical parameters. All other electrical parameters such as resistance and power are calculated from these two parameters. Common measurement techniques include: peak value, root-mean-square (RMS), average, and time integration. Peak value measurements are more sensitive to potential changes in the welding process and noise spikes. RMS, average, and integration measurements filter out the noise spikes, but may mask potential weld quality information [3]. Many researches have been carried out on the welding quality and monitoring. The on-line quality monitoring technique was described to detect susceptibility of welding defect formation by using real time monitoring of welding parameters: Arc voltage, Work angle and traveling angle SMAW (Shielded metal arc welding process) was selected in this study [4]. The on-line quality monitoring system based on data mining (DB) technology was established, the system was set up with client/server architecture [5]. A new approach for real-time weld quality monitoring was proposed based on the combination of optical sensors with fuzzy logic classification algorithms. The sensing hardware encompassed A/D converters and photodiodes measuring the radiations emitted by the plasma surrounding the welding arc. The measured data was then filtered and processed to determine in real-time indices of local quality of the welding process. These indices were then fed to a fuzzy system, which provides an index of the overall quality of the weld, classifying type and position of specific events (e.g. anomalies in the current, voltage or speed of the arc, contamination with other materials, holes) [6]. An efficient approach was presented to identify the stability and quality of short-circuit gas metal arc welding (GMAW) by using power spectral analysis and time-frequency spectral analysis methods. A systematic analysis based on experimental data showed that the short circuiting frequency is a determining factor on weld process stability. The relationship between the short-circuiting frequency and the process stability was established [7]. The theory of stochastic processes was applied to the analysis of gas metal arc welding data. A theoretical approach is presented and some of the commonly assumed hypothesis of process stationarity and ergodicity are verified for the data collected from stable processes adjusted for short circuiting and spray modes of metal transfer [8].

2. Monitoring of Fusion Arc Welding

Monitoring fusion arc welds is becoming more important as humans are becoming more-and-more remote from the actual welding operation. Many new systems are being developed to monitor automated or non-automated welding processes in real-time (on-line) or off-line. In general, monitoring methods can be divided into two classes: model based methods and feature based methods. Model – based methods have two significant limitations. First, many processes are non – linear time variant systems; this makes them difficult to model, and secondl, the signals obtained from sensors are dependent on a number of other factors. Feature –based monitoring methods use suitable features of sensor signal to identify the process conditions. These features could be derived from the current and voltage or from speed welding conditions [9]. For the purpose of increasing evidence that the precision of diagnosis and the fact that the process under way is correct, a number of welding samples that undergo a destructive testing (Bending and tensile test) and non destructive test (Hardness test) have been selected. Selection of appropriate neural network technique will be a new and effective measure added to the above-mentioned steps to obtain an intact diagnosis of the quality status.

In the area of Shield-Metal Arc Welding (SMAW) techniques, process monitoring and defect-detection methods play a fundamental role in improving the quality and the result at reduced manufacturing costs. The invention provides an arc welding monitoring device by which it is possible to find easily how to detect data such as a welding current and a welding voltage that correspond to the speed of the electrode filler. In monitoring arc welding, an arc welding monitoring device is disclosed. This device comprises a means for detecting a welding current or an arc voltage, and A/D converter for converting analog output of detecting means to digital signals in terms of a sampling frequency, a means for setting an operator period and fluctuation pitch to obtain a fluctuation mean, a means for setting a monitoring value to monitor the fluctuation mean value of the welding current or arc voltage, a means for judging welding conditions or welding results by comparing the fluctuation means value of the welding current or arc voltage with monitoring values, and a means for displaying and outputting the judgment result of the judging means. Recent successes in employing artificial neural network models, an artificial neural network (ANN) is a mathematical model or computational model based on biological neural networks. It consists of an interconnected group of artificial neurons and processes information using a connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure in accordance with external or internal information that flows through the network during the learning phase [10].

3. Experimental Work

Experimental work was carried out according to a plan developed to monitor and control fusion arc welding process, as shown in figure (1). It begins by performing a welding process monitored by an electronic system followed by destructive and non-destructive tests to investigate quality control on welded specimens. The obtained data are then processed through the use of neural network model designed to control the arc welding process.

Several equipments were used to accomplish the experiments and tests of the present work see figure (2):

1. Current Sensor.
2. Voltage Transformer and Amplifier.
3. Multi channels digital storage oscilloscope.
4. OTC AC Arc welder – KR 300 shielded metal arc welding machine.
5. Personal Computer (PC).
6. Tensile instrument and tensile test assembly.
7. Bending instrument and bending test assembly.
8. Hardness instrument and hardness test assembly.

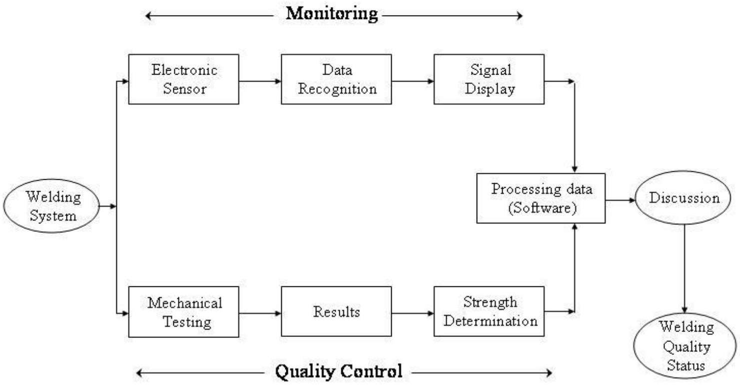

Fig.1. SMAW and Quality Monitoring and Control (Experimental Plane)

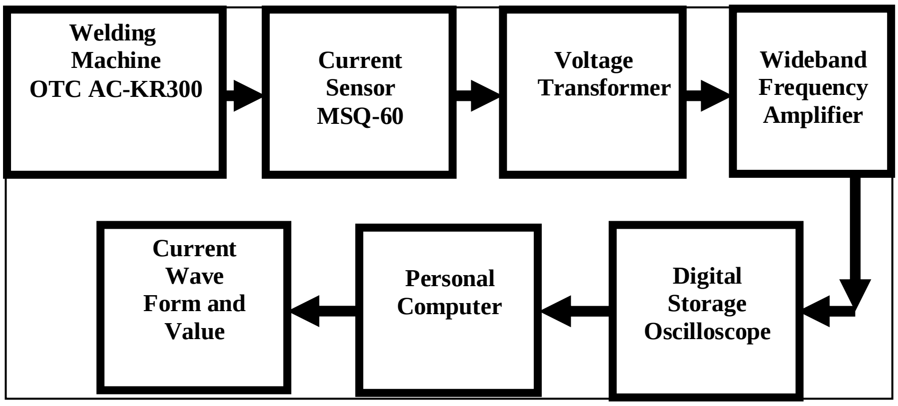

Fig.2. Diagram of Arc Welding and Monitoring Components

4. Experimental Setup and Operations

The details of experimental set up, instrumentation and the procedure of working operation are listed below:

1- Select a non–Galvanized steel sheet ASTM BN1323 with 6mm thickness with mechanical properties shown in table (1). We fixed the sheet by a suitable device in a horizontal level, prior to the welding process.
2- Clean the joint area where the welding will be done between the two metals to remove any surface contaminants.
3- Select a suitable electrode wire type ISO 2560/E 430 with diameter of 4 mm; the electrode should be positioned in a perpendicular position to the work piece with 30 degrees between it and the work piece at travel direction.
4- Select different welding conditions for each case (current, voltage, and travel speed) as shown in table (2).
5- The AC power voltage supplied for the machine must be uniform.
6- The welding type is Square butt joint as shown in figure (3).
7- The work piece must be cooled naturally after welding.
8- Meanwhile, during each welding cycle, the welding current form displays on a computer or on an oscilloscope. This behavior of current related to welding process will present the relation with the weld quality.
9- Destructive (tensile and bending test) and non-destructive (hardness) tests were performed to check weldment durability and strength. Force is applied to the specimens by hydraulic system. While applying the force, the operator continues watching force and strain scales until failure occurs. At this moment, the reading should be immediately recorded.

Table 1,
Mechanical Properties for the Base Metal Represented in Mechanical Tests

Mechanical test type	Hardness test HV	Tensile strength N/M2	Bending stress N/M2
Mechanical test value	122	27.916	749.57

Table 2,
Practical Work Condition

Weld No.	Voltage Range Setting (Volt)	Current Range Setting (Ampere)	Welding Travel Speed (mm/sec.)
1	30	100	5.19
2	45	150	4.53
3	60	200	5.93
4	75	250	7.16
5	90	300	10.52
6	30	100	2.66
7	45	150	1.94
8	60	200	2.98
9	75	250	2.04

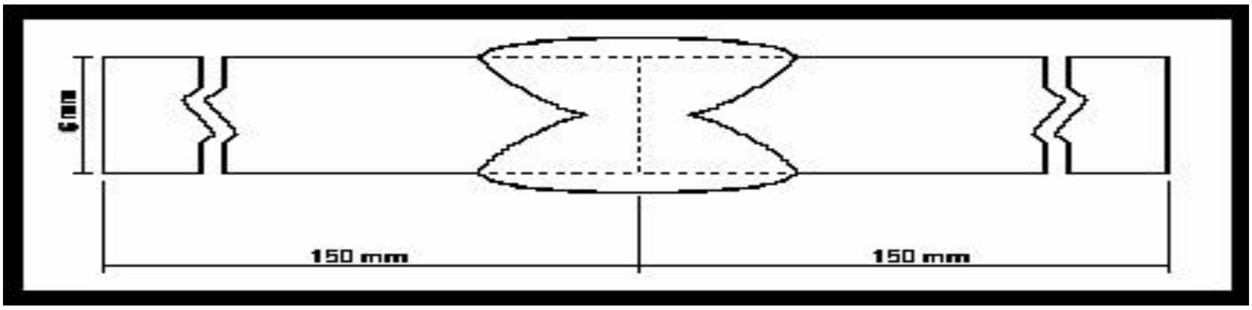

Fig.3. Square Butt Joint

5. SMAW Monitoring Using Neural Network

To develop a neural-network model, the input and the output parameters of the component should be identified in order to generate and preprocess data, and then use the data to carry out ANN training. For the purpose of performing reliable processing on the results obtained in this research, a neural network has been established to develop ANN model utilizing quality parameters (welding tensile strength, welding bending strength, and hardness of HAZ).

The first step toward developing a neural model is the identification of inputs and outputs. Determination of output parameters are based on the purpose of the neural-network model. The input output variables, number of nodes and activation functions are shown in figure (4), in which the input variables are welding voltage, welding current and welding travel speed, therefore a number of input nodes is set to 3. Output variables are welding tensile strength, welding bending strength and hardness. Therefore a number of output nodes is set to 3. There are two hidden layers and the number of nodes is set to 5 and 3. Log-Sigmoid is used as activation function for hidden layer No.1 and 2 and as a pure line function for output layer. Levenberg - Marquardt (LM) is used as a training method, where ten experimental sets are taken as training data. Eventually, ANN programs are created by MATLAB (V7).

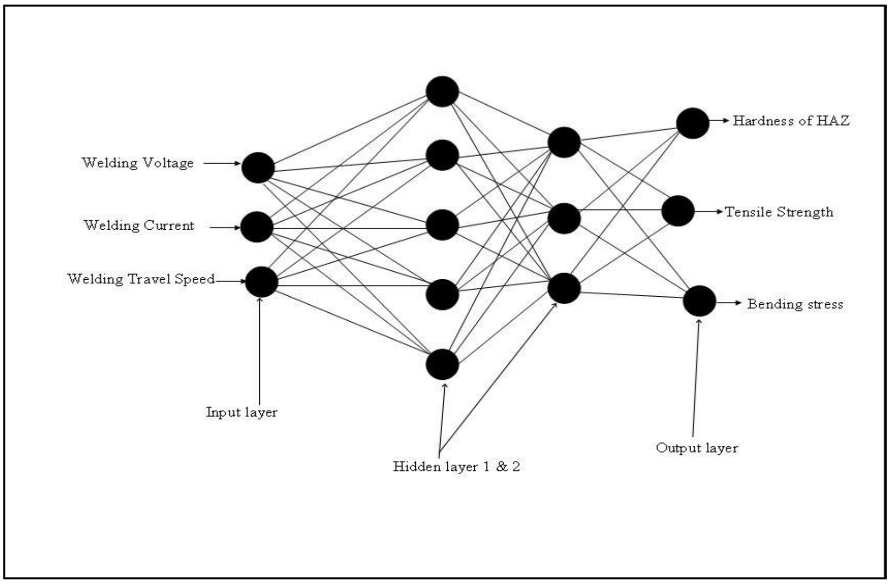

Fig.4. Developed ANN Model Utilizing Quality Parameters (Current, Voltage, and Travel Speed).

6. Results and Discussions

The experimental work on welding showned several practical variables and it gave clear indications for welding quality precept and resulting mechanical properties. These variables are: Tensile test readings obtained at failure, bending test readings obtained at failure, and Hardness test reading obtained at heat effected zone.

Quality monitors and control processes have been implemented by adopting variable welding conditions in order to know the result of changing these conditions on weld quality. Welding conditions include: voltage range setting, current range setting, and welding travel speed. Figures (5) to (10) show the relationhip between weld current and mechanical properties of a welded sheet (tensile strength, bending stress, and hardness of the heat affected area) at two different average travel speed of 7.704 mm/sec. and 2.405 mm/sec. These curves showed clearly the recommended current point for its conditions. We can show that the rates of welding quality parameter in general increase with the increase of voltage and current to a certain limit after that the increase in voltage and current causes a decrease of welding quality parameter because of the high temperature produced in the welding process that causes the melting of the work piece partially or completely at the joint line. This case is used normally in cutting material using welding machine. After verifications, it was noticed that the main reason for strength decline in tensile and bending test values is due to the variations in welding conditions. Hence, for the purpose of achieving acceptable levels of quality, it is recommended to check and diagnose the negative effects in each welding process and then modify the welding terms accordingly. Thus, it is observed that there is a relationship between the monitored current values and the welding conditions, which showed a clear advantage of the current monitor.

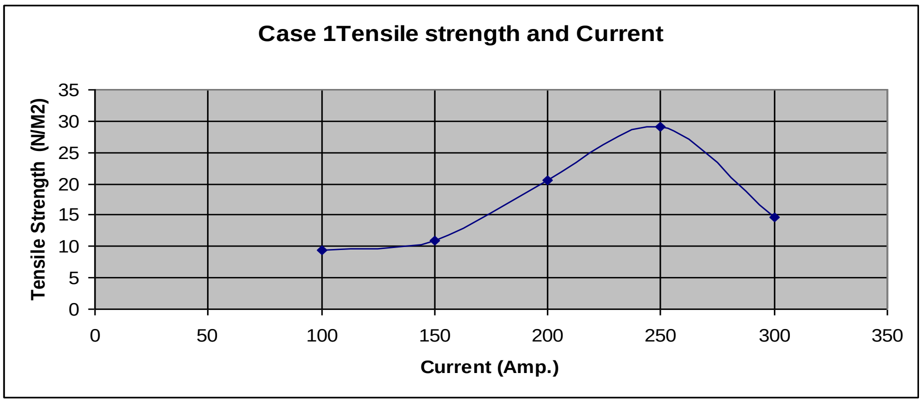

Fig.5. Effect of Weld Current on Tensile Strength at Weld Travel Speed (7.704 mm/sec)

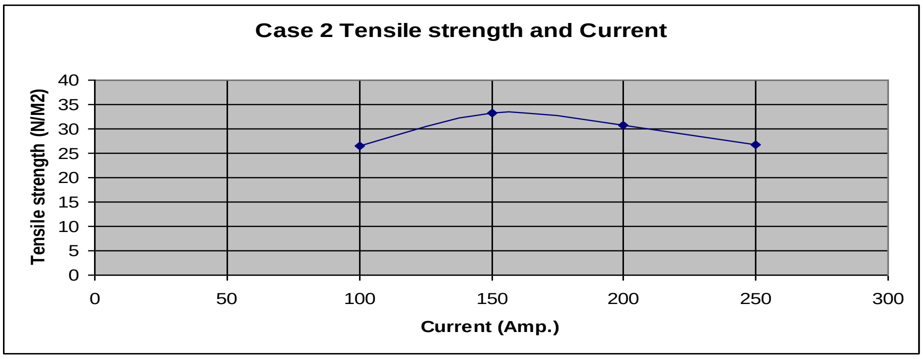

Fig.6. Effect of Weld Current on Tensile Strength at Weld Travel Speed (2.405 mm/sec)

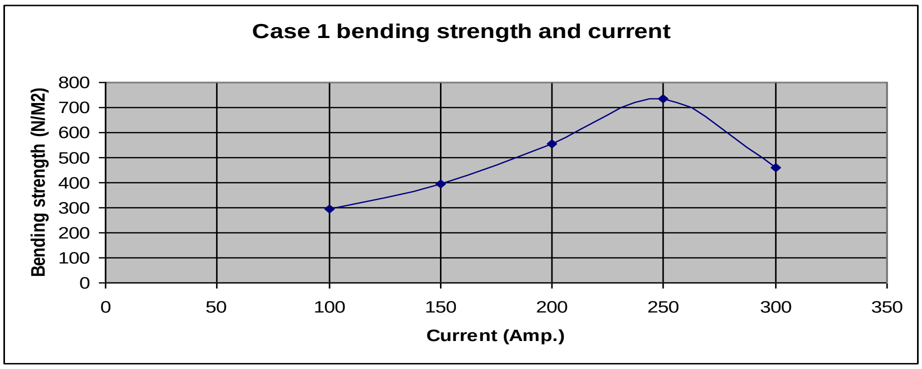

Fig.7. Effect of Weld Current on Bending Stress at Weld Travel Speed (7.704 mm/sec)

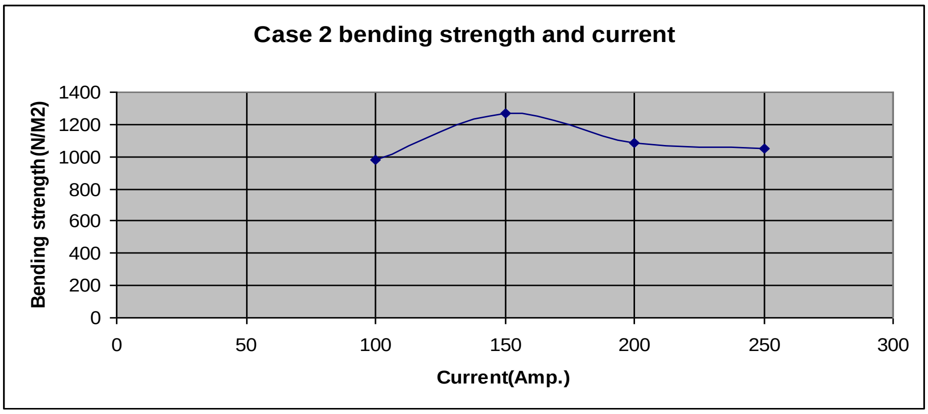

Fig.8. Effect of Weld Current on Bending Stress at Weld Travel Speed (2.405 mm/sec)

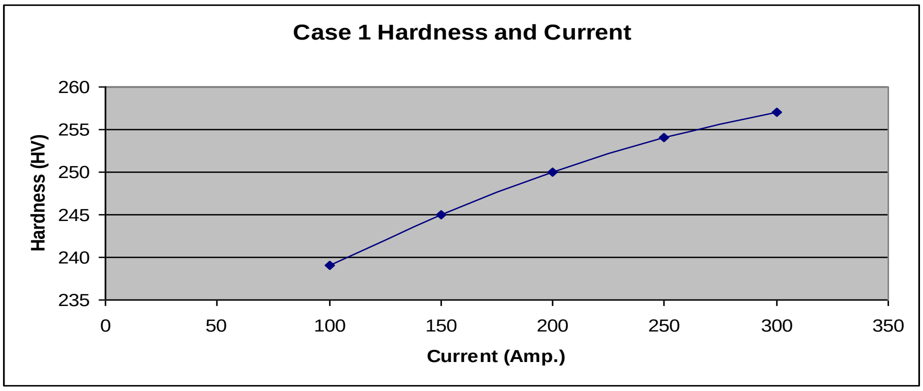

Fig.9. Effect of Weld Current on Hardness of HAZ at Weld Travel Speed (7.704 mm/sec)

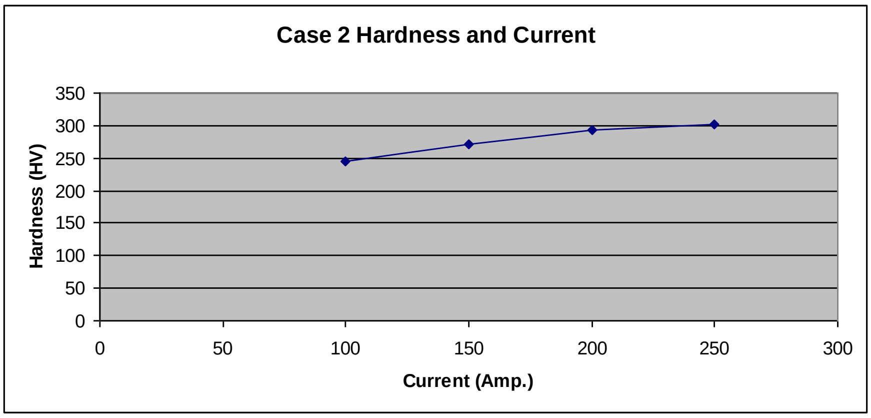

Fig.10. Effect of Weld Current on Hardness of HAZ at Weld Travel Speed (2.405 mm/sec)

Welding operations showed that changing the setting of the current range on the welding machine did not necessarily indicate the precise value of the current, which was concretely consumed during the implementation of the welding operation. The current monitor can do this task instead of the welding machine and precisely detect and display the welding current value. Here, it is important to mention that the welding current value is falling as a key factor in determining the welding quality. Figures (11)-(16) show the monitoring instantaneous current oscillation with a sample of welding at different welding conditions. We can see that the amplitude of welding current is varying in ripple form that is caused by an unsteady state condition of welding like the distance between electrode and work piece surface, cleaning of surface and its effect on conductivity, the length of the electrode that is reduced in welding process and any change in the speed and the direction of the electrode or the electrode feed. All of these caused this ripple in the current and then had an effect on the welding quality.

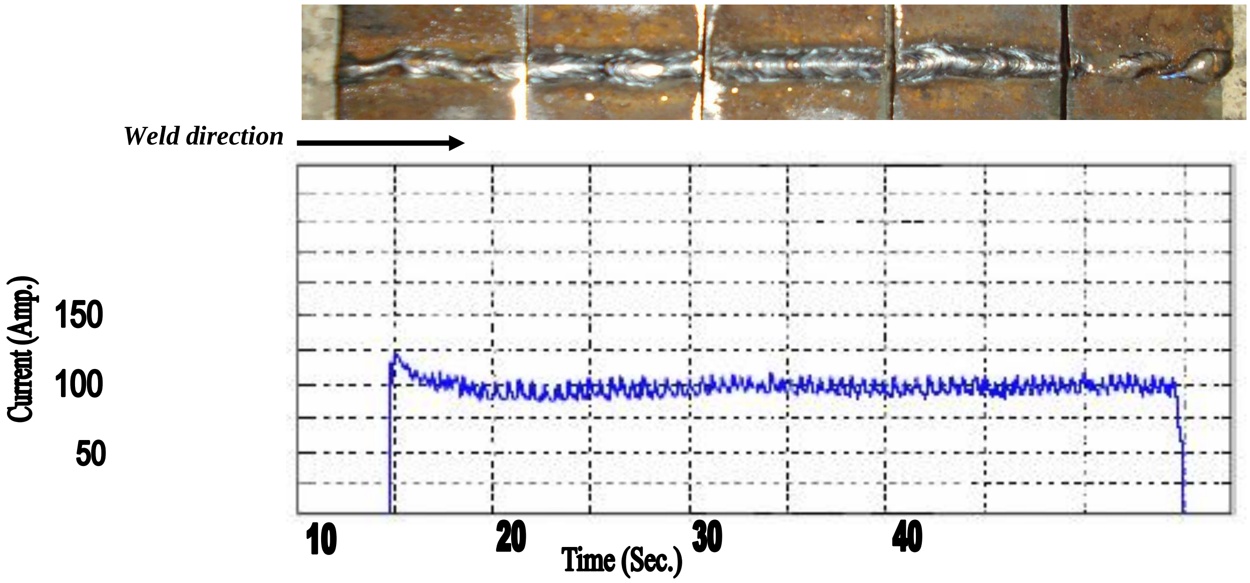

Fig.11. Instantaneous Current Value in Welding (I= 100 Amp, V=30 Volt, Vw= 5.19 mm/sec)

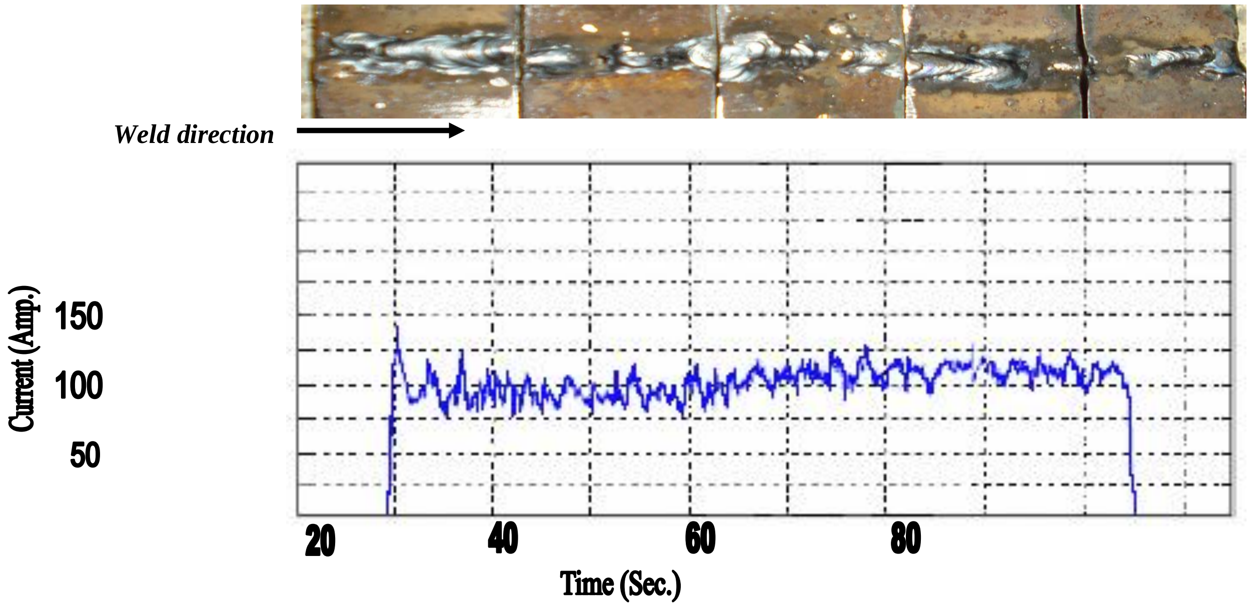

Fig.12. Instantaneous Current Value in Welding (I= 100 Amp, V=30 Volt, Vw= 2.66 mm/sec)

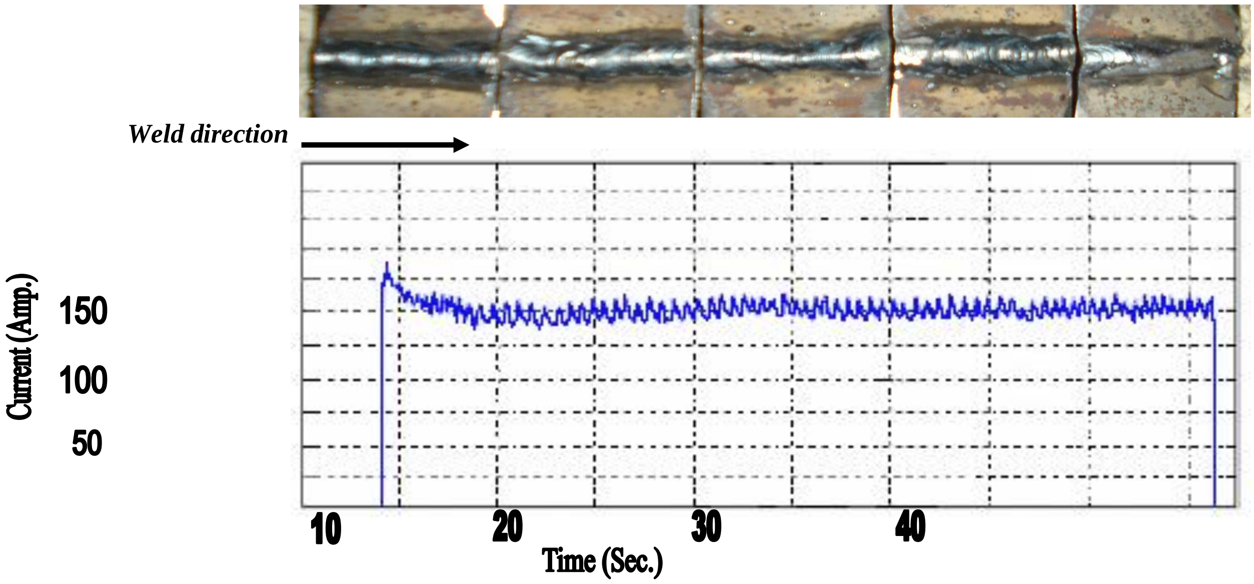

Fig.13. Instantaneous Current Value in Welding (I= 150 Amp, V=45 Volt, Vw= 4.53 mm/sec)

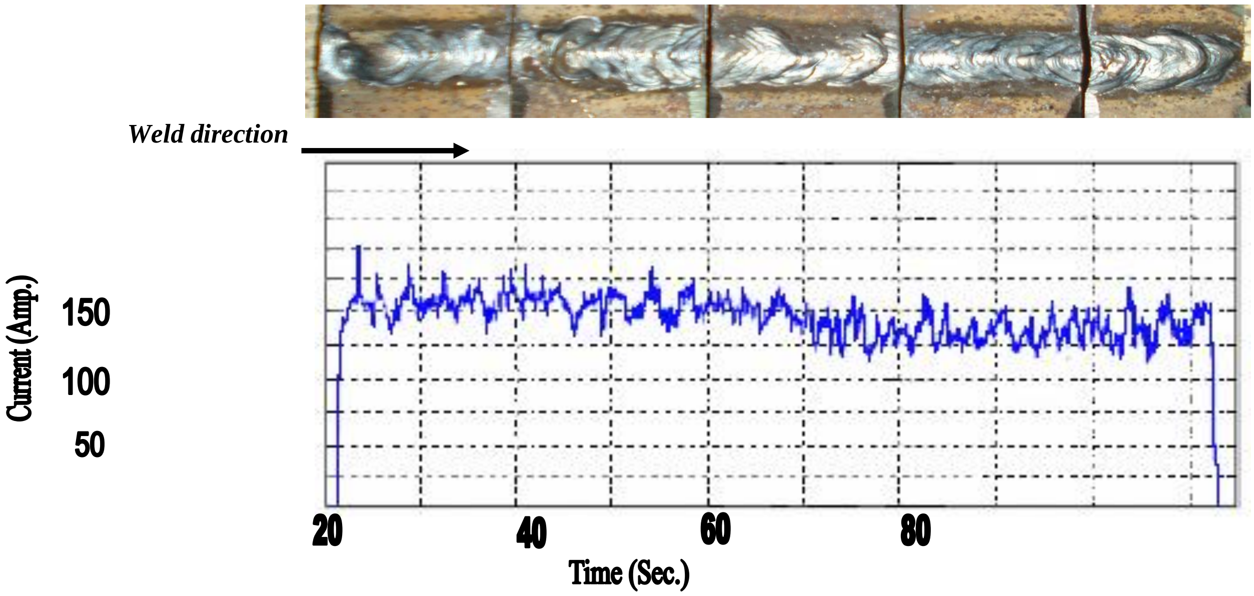

Fig.14. Instantaneous Current Value in Welding (I= 150 Amp, V=45 Volt, Vw= 1.94 mm/sec)

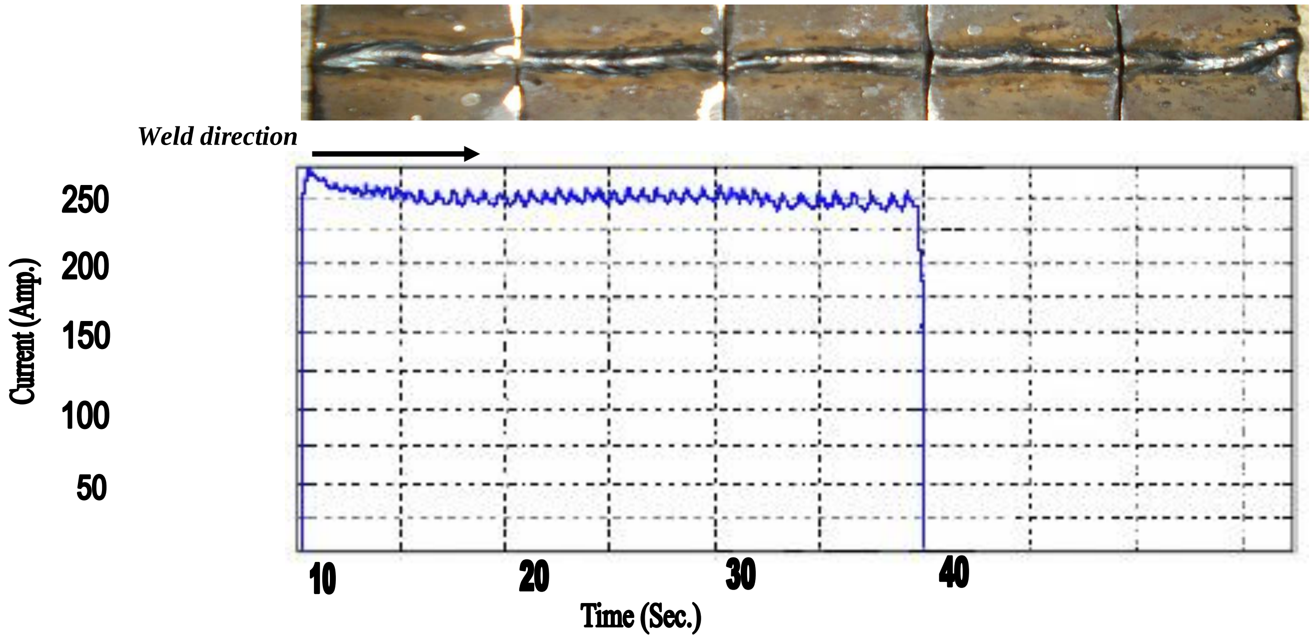

Fig.15. Instantaneous Current Value in Welding (I= 250 Amp, V=75 Volt, Vw= 7.17 mm/sec)

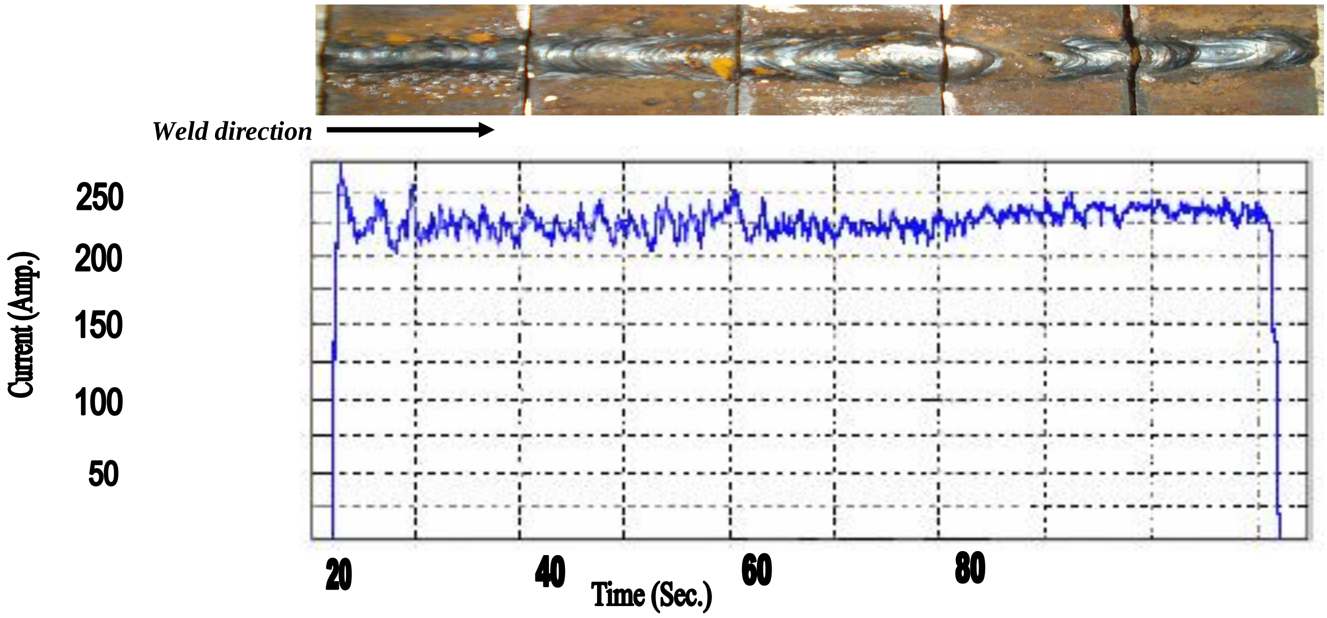

Fig.16. Instantaneous Current Value in Welding (I= 250 Amp, V=75 Volt, Vw= 2.04 mm/sec)

To investigate that the monitoring current represented a good indication of the weld quality, we made an artificial failure prior welding process by making a holes in a joint line between two plates or introducing intermetallic components, inclusions, or thermal stresses in the joint line and then welding the joint. We noticed a great change in the current ripple values at these failure regions as shown in figures (17) and (18).

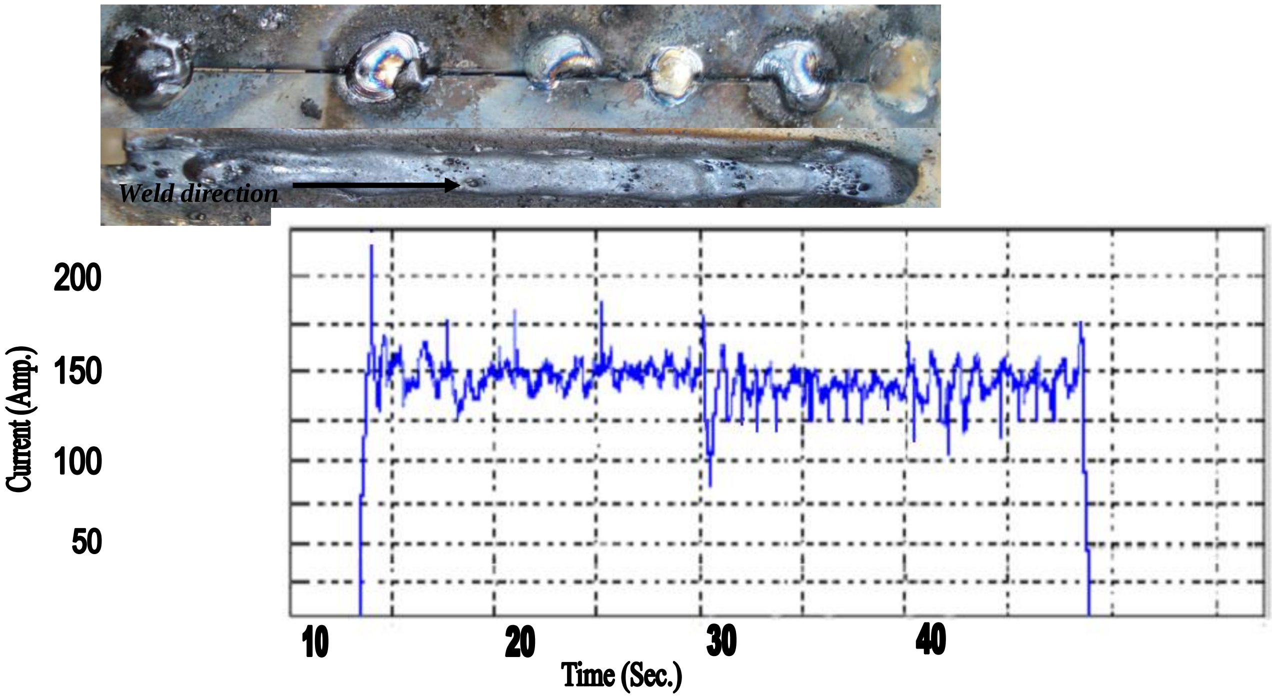

Fig.17. Monitoring Defect in Welding (Vacancy)

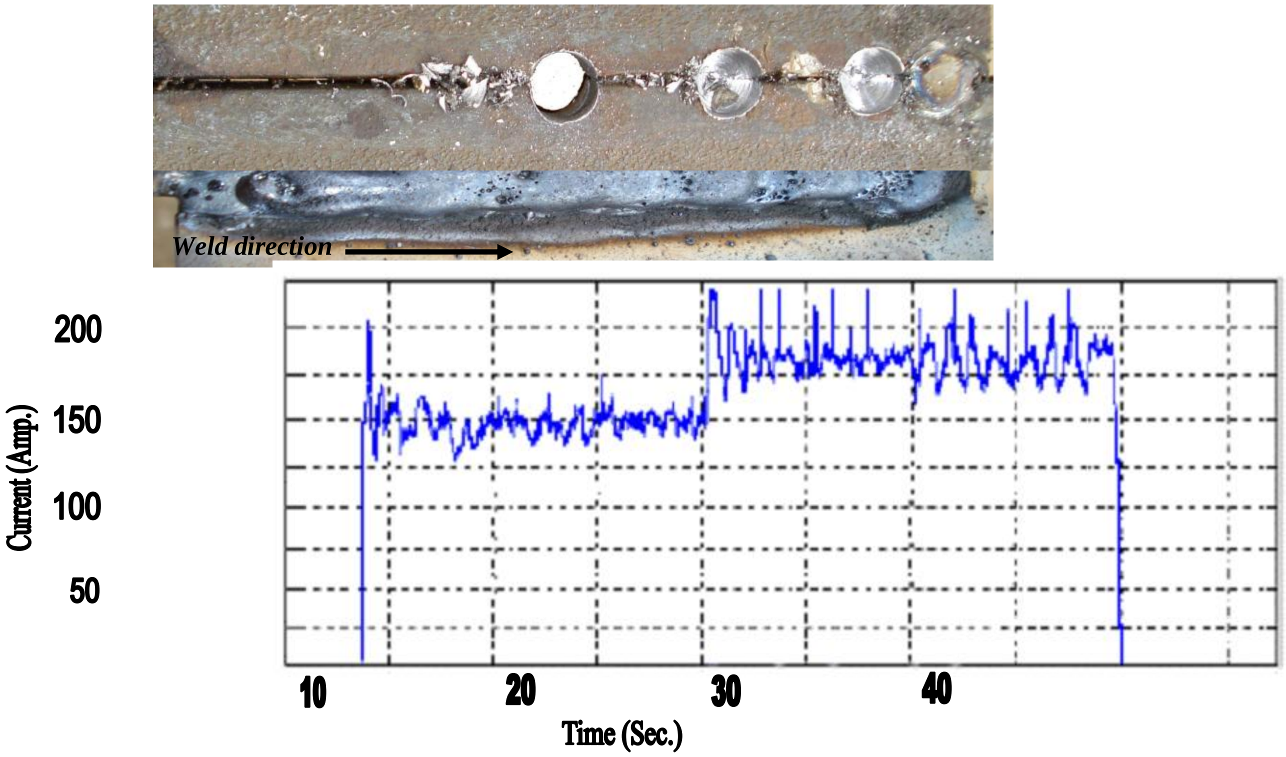

Fig.18. Monitoring Defect in Welding (Hard Particle)

ANN was developed utilizing quality parameter (welding voltage – welding current – welding travel speed). Making use of experimental result data (tensile strength, bending stress and hardness of HAZ) has trained a neural network for a process model, which can predict the level of quality for different welding conditions as shown in tables (3) and (4). The training curve of the network is shown in figure (19). Running the network gives an important advantage showing its ability to predict additional readings of quality parameter besides the original ones obtained from the experimental work upon inserting new interface values of welding conditions taken within the employed ranges. It will be noticed that the network also predicts new interface reading of quality parameter (Tensile and Bending test value and finding the effect of heat at hardness of HAZ) approaching the values to those obtained from the experimental runs.

Welding conditions and quality parameters are the name of the neural networks which have been trained to a set of data derived from the practical experimental runs, that makes the networks ready to receive new data for subsequent prediction. New data should be accordingly set as input parameters, which represent only the welding conditions within the limits adopted in this study. Consequent outputs are new rates that represent only quality parameters which are predicted by the pre-trained neural networks. It is clear that agreement of the total values and convergence readings of each set shows that the trained neural networks are ready to predict quality parameters whenever it is required. Some network results were found far from reasonable values due to inadequate neural network training data, because of the limited number of samples and need for modern instrument to reduce the time of testing samples.

Table 3,
ANN 1 Output Utilizing Quality Parameters (Tensile and Bending Strength Test Value at Failure – Hardening Effect Value)

Input No.	Voltage setting (volt)	Current setting (Amp.)	Speed of welding (mm/sec)	Hardness of HAZ (HV)	Tensile strength (N/M^2)	Bending strength (N/M^2)
1	30.0000	100.0000	4.5	242.9536	9.1614	290.9129
2	36.6667	122.2222	5.2	244.4841	9.7385	309.1162
3	43.3333	144.4444	5.8	246.0196	10.2963	327.3195
4	50.0000	166.6667	6.5	247.5610	10.8632	345.5228
5	56.6667	188.8889	7.2	249.1835	11.4391	363.7261
6	63.3333	211.1111	7.8	250.6260	11.9861	381.9294
7	70.0000	233.3333	8.5	252.1486	12.5631	400.1327
8	76.6667	255.5556	9.2	253.6709	13.1289	418.3360
9	83.3333	277.7778	9.8	255.2154	13.6979	436.5393
10	90.0000	300.0000	10.5	256.7459	14.2638	454.7426

Table 4,
ANN 2 Output Utilizing Quality Parameters (Tensile and Bending Strength Test Value at Failure – Hardening Effect Value)

Input No.	Voltage setting (volt)	Current setting (Amp.)	Speed of welding (mm/sec)	Harness of HAZ (HV)	Tensile strength (N/M^2)	Bending strength (N/M^2)
1	30	100.0000	1.9400	235.7538	28.9437	991.6251
2	35	116.6667	2.0556	245.2694	29.3566	1008.1322
3	40	133.3333	2.1711	254.7849	29.7835	1025.2635
4	45	150.0000	2.2867	264.3005	30.1904	1042.7693
5	50	166.6667	2.4022	273.8161	30.5743	1060.2431
6	55	183.3333	2.5178	283.3316	31.0122	1077.4627
7	60	200.0000	2.6333	292.8472	31.4281	1094.2719
8	65	216.6667	2.7489	296.6070	32.3700	1081.7679
9	70	233.3333	2.8644	302.3667	33.7220	1069.2363
10	75	250.0000	2.9800	310.1265	34.8539	1056.6638

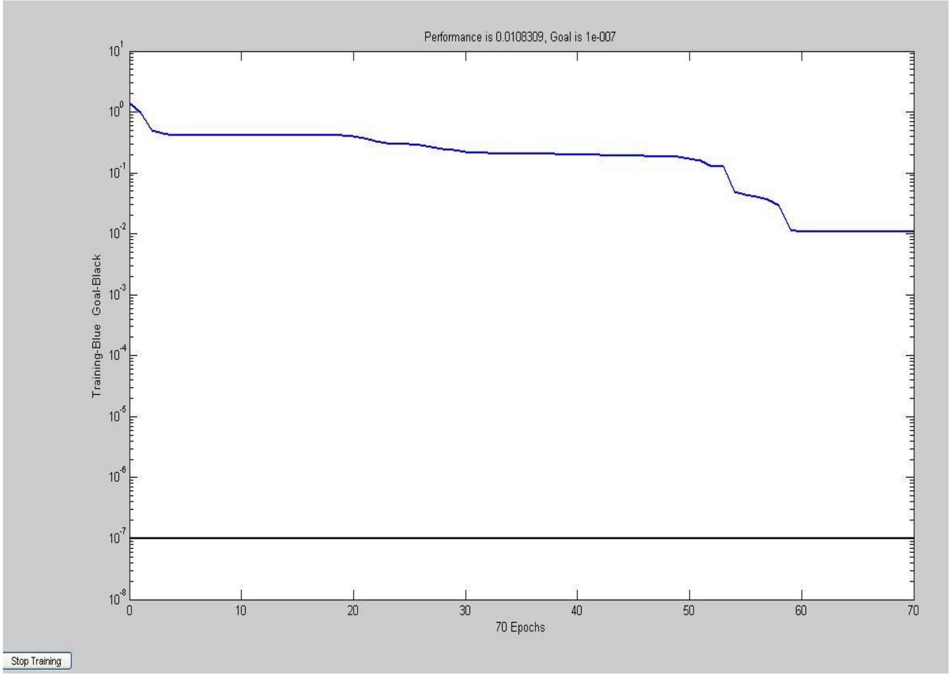

Fig.19. ANN Training Curve Utilizing Quality Parameters for Case 1

7. Conclusions

The main conclusions of this research in the field of SMAW Quality and Online Current Monitor System are as follows:

- The system has high response sensing capability which is needed to meet the requirements of SMAW monitoring process which can be installed directly to the welding machine and then to a computer without leaving a negative impact on the efficiency of the machine or causing a technical obstacle that prevents the operator from performing his duty well.
- It provides the operator with an opportunity to watch and monitor the welding current value for each welding trial individually from a distance no less than 5 meters.
- Record the current form at all welding processes and save it as image on the computer that perform the welding quality. This can be a certificate of the welding process.
- The system supports quality control procedures and welding productivity without the need to stop the production sequence or doing more periodic destructive mechanical testing to dozens of samples. Here, it can be noted which economical gains could be achieved in utilizing such electronic surveillance feature.
- Reduce the probability of welding failure and decide the weakness points and layers after checking the current response and delimitation of the defect region to be tested.
- The optimum parameters achieved (for welding 6mm thickness of non-Galvanized steel plate ASTM BN 1323 type and for welding a square butt joint using 4mm electrode diameter of ISO 2560/E 430 type) are 150 Ampere and 45 volt with 0.24 cm/sec for welding travel speed.
- ANN was a useful technique to predict the level of quality for different welding conditions utilizing quality parameter (voltage, current, travel speed) using experimental result data (tensile strength, bending stress, and hardness of HAZ). This ANN could predict any welding quality parameter for any welding condition within the range of previous input value.

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الأستقصاء عن أنظمة المراقبة و السيطـــره على عمليات اللحـــام بالقوس الكهربائي

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الخلاصة

إنّ مراقبة نوعيةَ وجودة اللحامِ مهمةُ جداً لأنها تزيد احتمالية الارباح الماليةَ وهذه تَحْدثُ خصوصاً في عمليات الأنتاج حيث ان اللحام المعيوبِ يذهب مع الخسائرِ في الإنتاجِ ويَستلزمُ معالجته خسارة في الوقتِ والكلفة.

هذا البحثِ يَتعاملُ مع مراقبة نوعية اللحام وقابليةِ التحكم في عمليةِ اللحام الأنصهاري بالقوسِ الكهربائي التي تَستعملُ شبكة عصبيةَ إصطناعيةَ (ANN) كنموذج.

تأثير عناصر اللحامِ على نوعيةِ اللحامَ دُرِسَ بتَطبيق نَتائِجِ تجريبيةِ تم الحَصول عليها مِنْ لحام صفيحة الفولاذِ (non- ASTM BN 1323 Galvanized) بسمك 6 مليمتر في ظروف اللحامِ المختلفةِ (تيار لحامِ، فولتية لحامِ، سرعة اللحامِ) تمت المراقبة بالأنظمةِ الإلكترونيةِ، ثم تُبعت بأختبارات فحص أتلافية لعينات (أختبار الشدّ والإنحْناء) وغيرأتلافية لعينات أخرى (أختبار الصلادة) لتَحرّي مراقبة الجودة على نماذجِ اللحام.

إنّ النَتائِجَ التجريبيةَ المكتسبةَ تمّ معالجتها بأدخالها لنموذجِ الشبكة العصبيةِ الإصطناعيةِ للسَيْطَرَة على عمليةِ اللحام وتوقّعُ مستوى النوعيةِ لظروف اللحام المختلفةِ.

إستُنتِجَ بأنّ ظروف اللحام (الفولتية، التيار، سرعة اللحام) كَانَت العوامل المهيمنة التي أَثّرتْ على نوعيةِ وقوّةِ اللحامَ. أيضاً وَجدنَاانه عند تحديد ظروف اللحام، كانت هناك سرعةُ لحام قصويةِ للحُصُول على نوعيةَ لحامِ قصويةِ.

يَدْعمُ النظامُ إجراءاتَ مراقبة الجودةِ و انتاجية اللحام بدون عَمَل إختبار ميكانيكي تدميري الى أكثرِ من العشراتِ من العيناتِ.
